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Performance Improvement of Shotcrete by Polymer Binder Modification

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Shotcrete for Underground Support XIV

Content

Application at a New Access Road to a Salt Mine in Stetten / Germany

Formulation for the Tests at Clarastollen Salzbergwerk Stetten

No.			2	1
Based on m³			Reference	ETONIS 3500
ETONIS® 3500			-	22
Sand 0/4			1077	1077
Grit 4/8			823	823
Riteno 5 CEM II B-T 52,2 N / Holcim			400	400
Flyash Safament			20	20
W/C - Ratio			0,47	0,47
Superplasticizer, on Cement		%	**0,72**	**0,38**
Retarder Retard 360, on Cement		%	*	*
Concrete Temperature		°C	13,5	13,5
Flow after plasticizer addition	cm	1 min	60	60
	cm	1h	58	56
Accelerator		%	12	12

Despite a Reduction in the Elastic Modulus, High Compressive Strengths are Achieved

	Reference concrete	Polymer-modified concrete	Polymer-modified concrete
Wacker Polymer	Without	Aqueous	Powder
Additive rel. to cement	0	5% (solid)	5% (solid)
W/C ratio	0.47	0.47	0.47
Temp. fresh concrete (°C)	12	20	12
Immediate slump	58 cm	55 cm	58 cm
Slump after 1 h	58 cm	55 cm	58 cm
f_{cyl} after 1 d (N/mm²)	**16.6**	**10.5**	**15.3**
f_{cyl} after 7 d (N/mm²)	17.0	22.1	17.1
f_{cyl} after 28 d (N/mm²)	**36.9**	**39.8**	**35.6**

Test results: Drill cores, 100 mm in diameter and 200 mm high

The Polymer-Modified Sprayed Concrete Withstands Water Ingress, no Stains

Standard formulation without polymer at **430** meter

- Typical water ingress & stains
- Wet surface

Formulation with polymer at **470** meter

- No water ingress
- No stains

First Inspection after 24 Month Duration - Dry
Inspection in October 2013, after 5 Years and Dry - Until Today

Water Tight Shotcrete Application at Hagerbach Test Gallery

Realistic Simulation of Water Pressured Condition in a Tunnel, to Test Waterproofing Performance

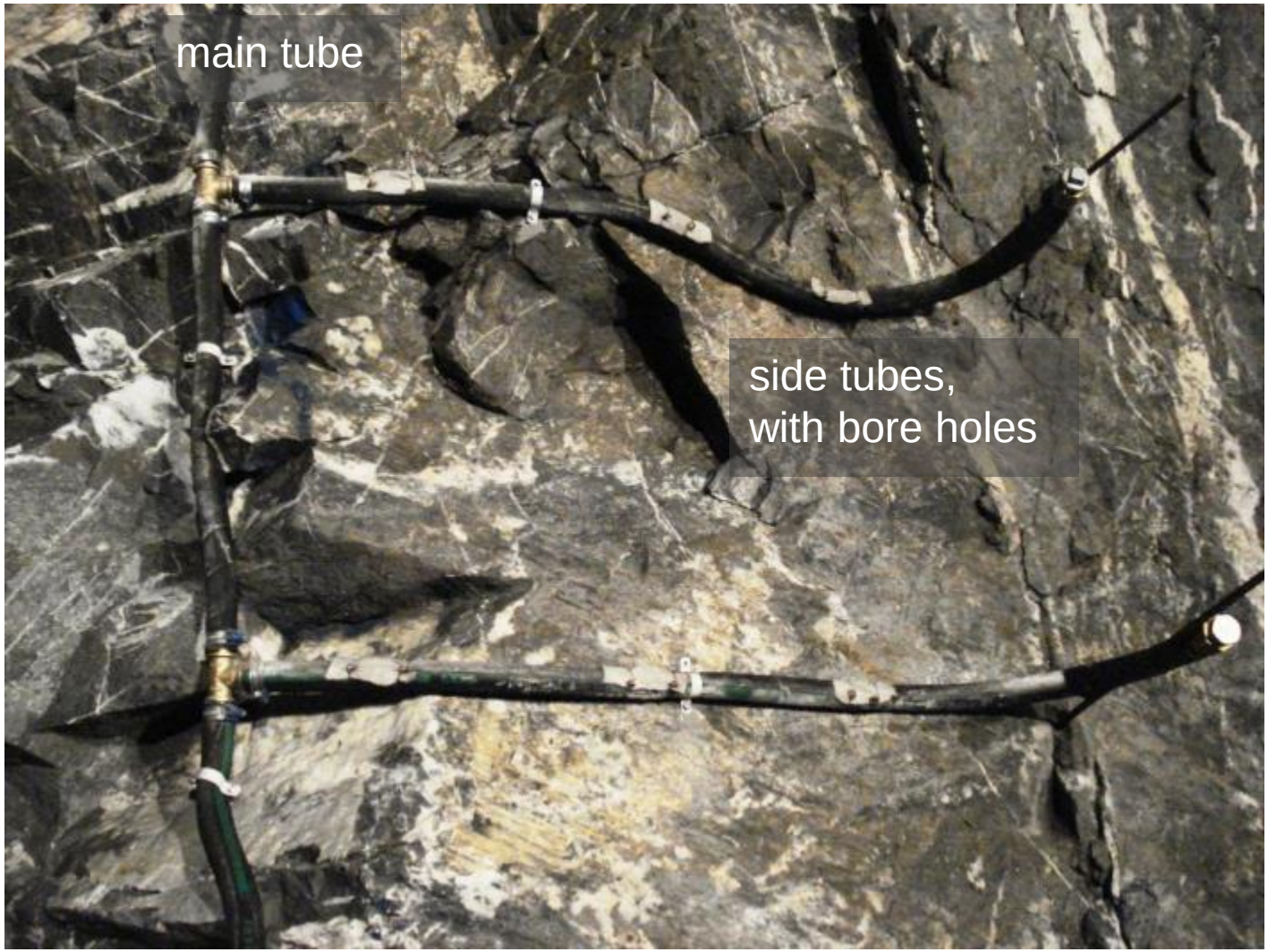
PE pipes are fixed at the rock surface and shotcrete is sprayed on top.

The pipes are between Rock and Concrete

Water was pumped into the pipes and the Concrete it wetted from the back side.

Cracks will become visible

Detailed Picture of the Tube Arrangement and Bore Holes



Water supply from the bottom up

The bore holes are covered by an porous fabric

Water Pressure tests performed by 1,5 bar and 6,0 bar

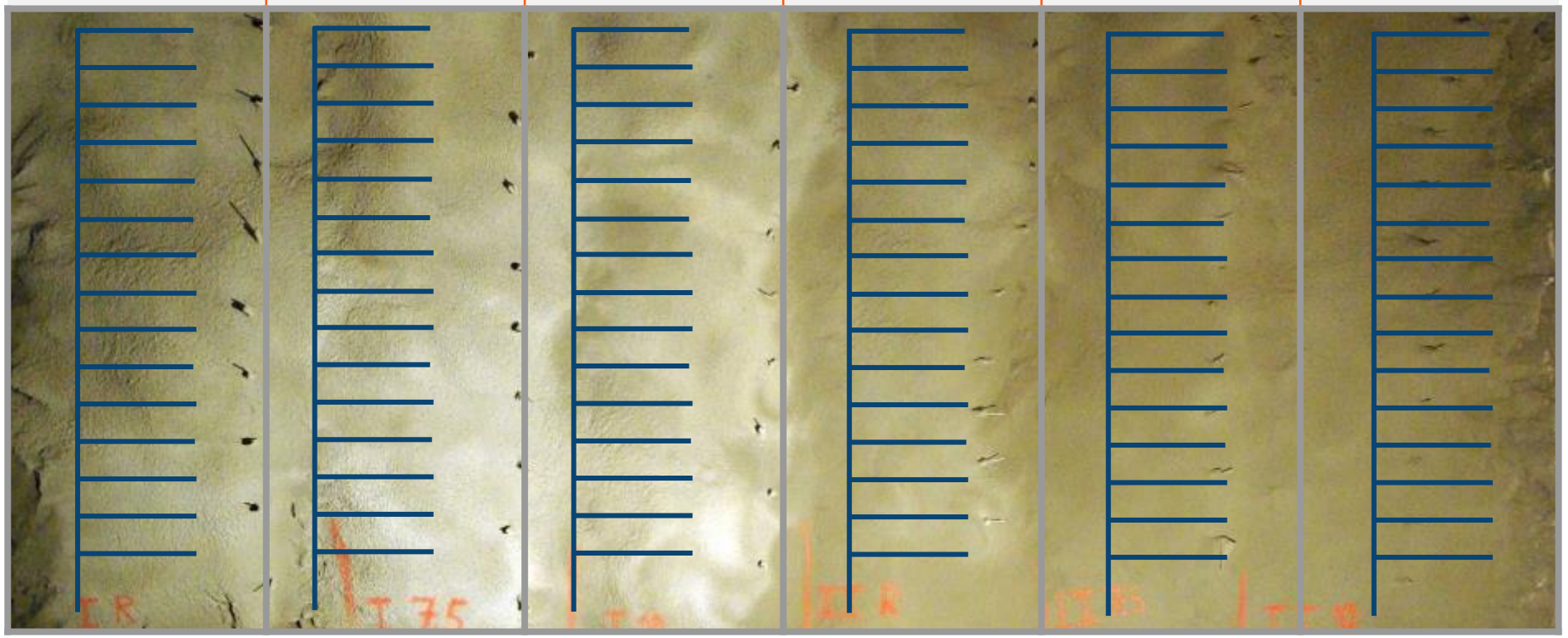
Wet Shotcrete Formulation

Section No.		1	2	3	4	5	6
Modification		Reference 0% Polymer	7.5% Polymer	10.0% Polymer	Reference 0% Polymer	7.5% Polymer	10.0% Polymer
VSH Test Report No.		FBK 2	FBK 3	FBK 4	FBK 5	FBK 6	FBK 7
Normo 4 CEM I 42.5 N	kg/m³	400	400	400	-	-	-
Fluvio 4 CEM II A-LL 42.5 N	kg/m³	-	-	-	400	400	400
0/1	kg/m³	133	133	133	133	133	133
0/4	kg/m³	1102	1102	1102	1102	1102	1102
4/8	kg/m³	665	665	665	665	665	665
Polymer binder (liquid)	% on cement	-	7.5	10	-	7.5	10
W/C	Ratio	0.47	0.48	0.47	0.46	0.43	0.45
FM Sika Viskocrete SC 305	% on cement	1.2	0.8	0.2	1.0	0.7	0.28
VZ Sikatard 903	% on cement	0.2	0.2	0.2	0.2	0.2	0.2

Completed Test Field: 0%, 7,5% and 10% Polymer on Cement CEM I and CEM II in Comparison

Test Field Completed, 6m x 2m, to Proof the Concept of Watertightness

No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
CEM I Normo 4	**CEM I** Normo 4	**CEM I** Normo 4	**CEM II** Fluvio	**CEM II** Fluvio	**CEM II** Fluvio
No polymer / reference	7,5% ETONIS 150	10% ETONIS 150	No polymer / reference	7,5% ETONIS 150	10% ETONIS 150



schematic water pipe arrangement behind the shotcrete

After 15 Weeks Pressure Increased from 1,5 Bar to 6 Bar and One Day In-between

- 10% Polymer dosage performed best
- Water tightness visible

Test Results
Visual Assessment over Time

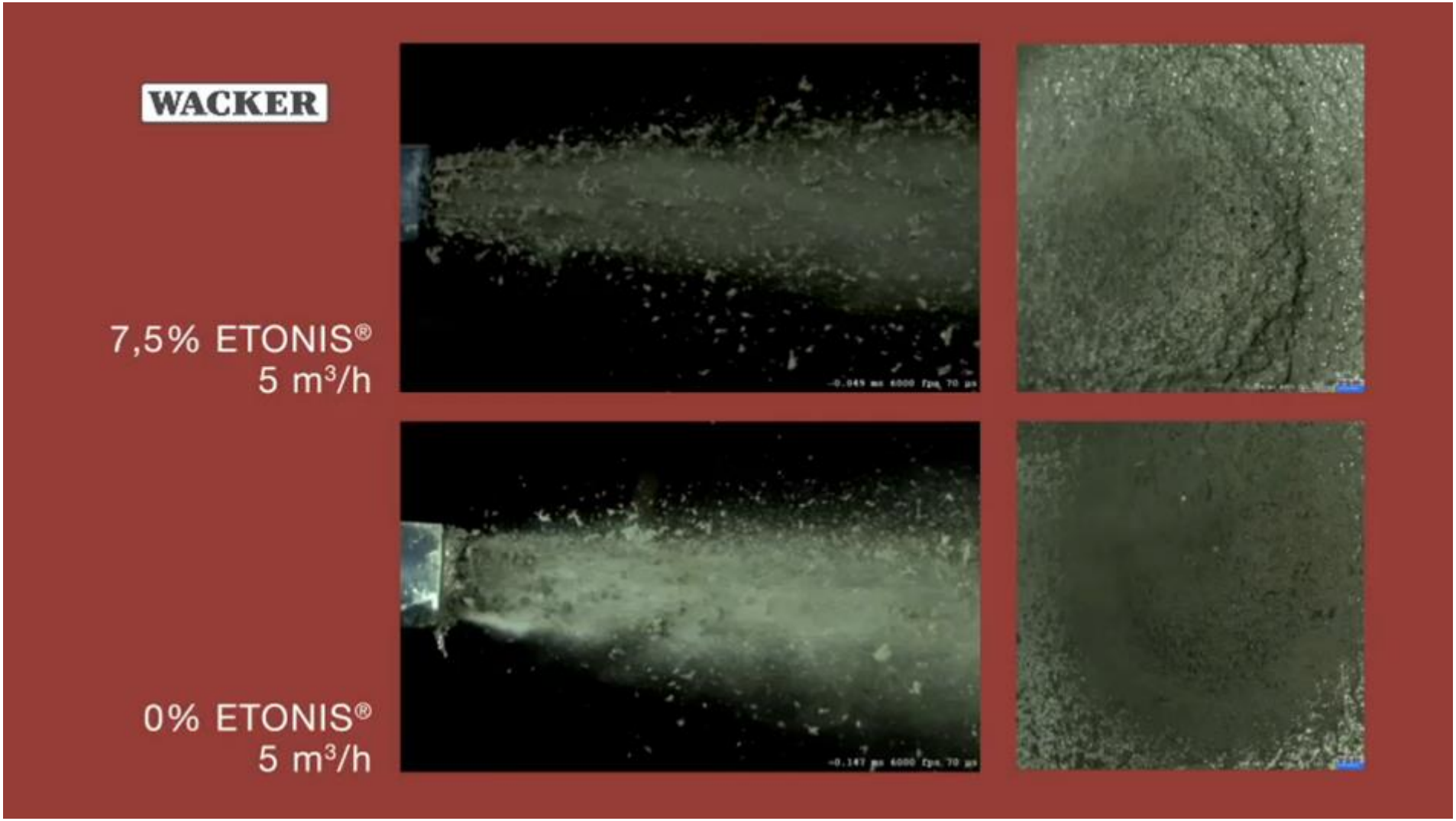
Section No.			1	2	3	4	5	6
Modification			Reference 0% Polymer	7.5% Polymer	10.0% Polymer	Reference 0% Polymer	7.5% Polymer	10.0% Polymer
Test Report No.			FBK 2	FBK 3	FBK 4	FBK 5	FBK 6	FBK 7
Test Time	Duration	Pressure						
1 week	7 d	1.5 bar	Dry	Dry	Dry	Dry	Dry	Dry
2 weeks	7 d	1.5 bar	Dry	Dry	Dry	Dry	Dry	Dry
4 weeks	14 d	1.5 bar	Dry	Dry	Dry	Dry	Dry	Dry
6 weeks	14 d	1.5 bar	Wet	Dry	Dry	Wet	Dry	Dry
10 weeks	28 d	1.5 bar	Wet	Dry	Dry	Wet	Dry	Dry
15 weeks	35 d	1.5 bar	Wet	Dry	Dry	Wet	Dry	Dry
16 weeks	7 d	6.0 bar	Wet	Wet	Dry	Wet	Wet	Dry
20 weeks	28 d	6.0 bar	Wet	Wet	Dry	Wet	Wet	Dry

High-Speed Camera Monitoring of Shotcrete Application

Formulations Tested

Product	Dosage	Reference Formulation No. 1	Polymer Formulation No. 3
Sand 0/1	kg	115	125
Sand 0/4	kg	1022	1040
Gravel 4/8	kg	587	591
CEM I 42.5 N (Normo 4)	kg	450	450
Viscocrete SC 302	1.00 % / 0.22% without / with polymer	5.00	0.90
Water (added)		141	130
Polymer	7.5% / 10.0% on cement	-	33.75 / 45.00
Concrete temperature, °C		15.5	15.5
Air pore content of the concrete in %		5.8	5.5

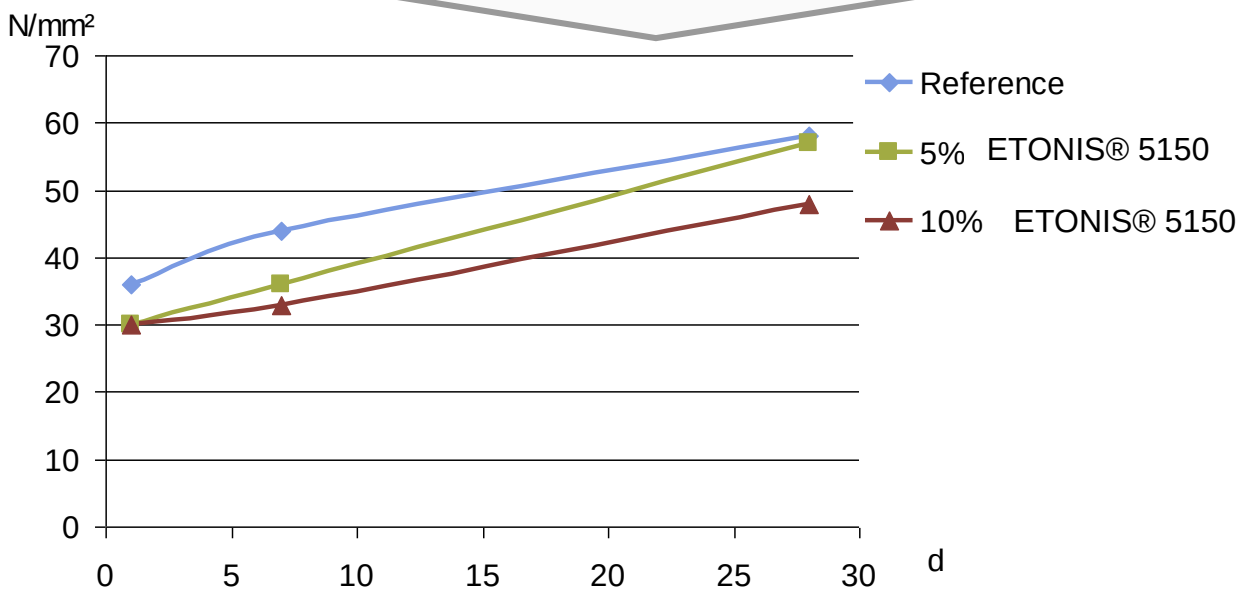
Impact of Polymers on Droplet Formation



Application at a Pressure Water Tunnel in Hintermuhr / Austria

Strength Performance after 1d, 7d, 28d

Confidential Formulation		Reference	5% Dispersion	10% Dispersion
"Hilti-Bolzenschuss" 24h	**1d N/mm² ***	36	30	30
1d dry / 6d wet	**7d N/mm² ****	44	36	33
dencity	kg/m³ **	2300	2310	2290
1d dry/ 6d wet / 21d dry	**28d N/mm² ****	58	57	48
Dencity	kg/m³ **	2260	2280	2250

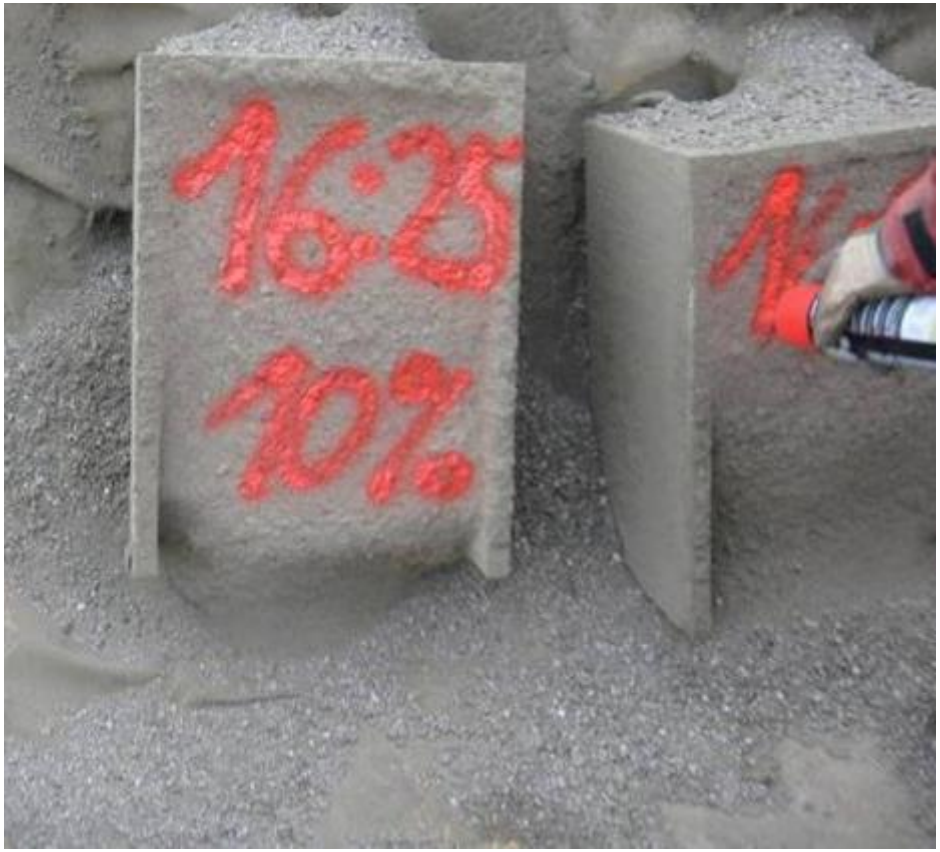


* Frühfestigkeitsbestimmung
Hilti-Bolzenschuss nach 24h
** Bohrkerne 50 x 100 mm,
getestet von bvfs Testinstitut / Salzburg

Application of Polymer Modified Sprayed Concrete

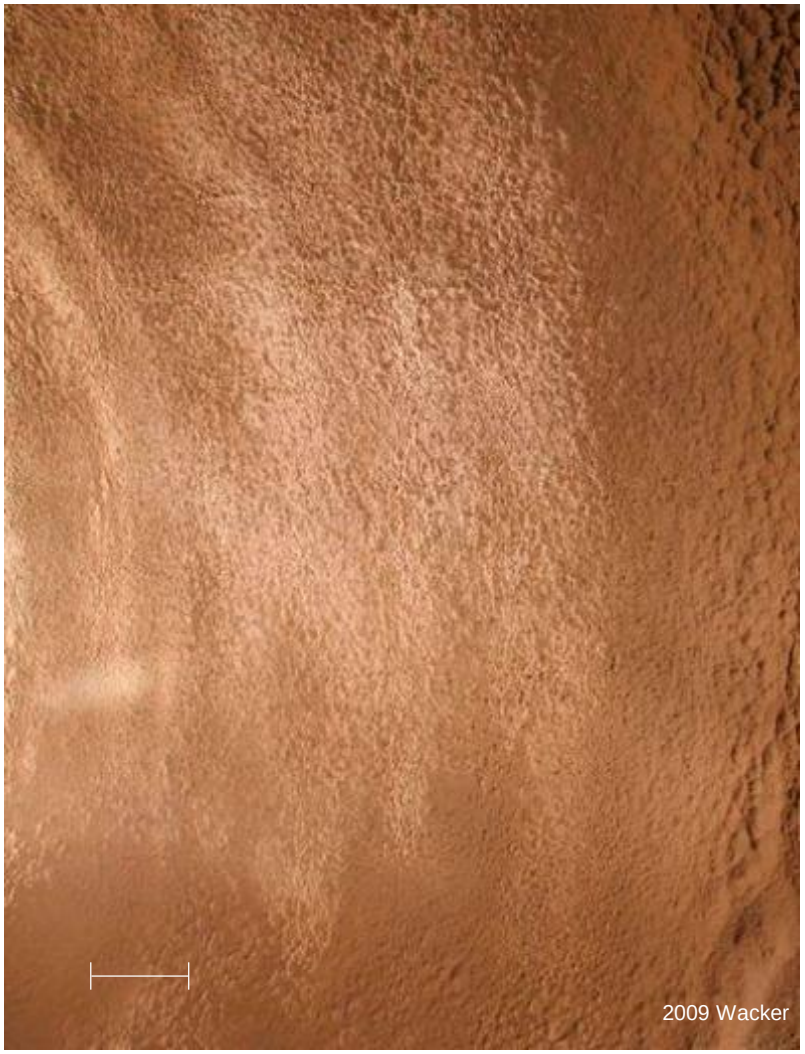
Clearly Visible Difference of the Rebound by Polymer Modification

- Reference concrete - without Polymer
- High rebound and dust formation



- 10% Polymer modification
- Very low rebound and dust formation

2009 / 2011: Shotcrete Surface, Inspection after two Year's of Operation, next inspection 2020/2021



Application at a Water Canal Near Munich / Germany

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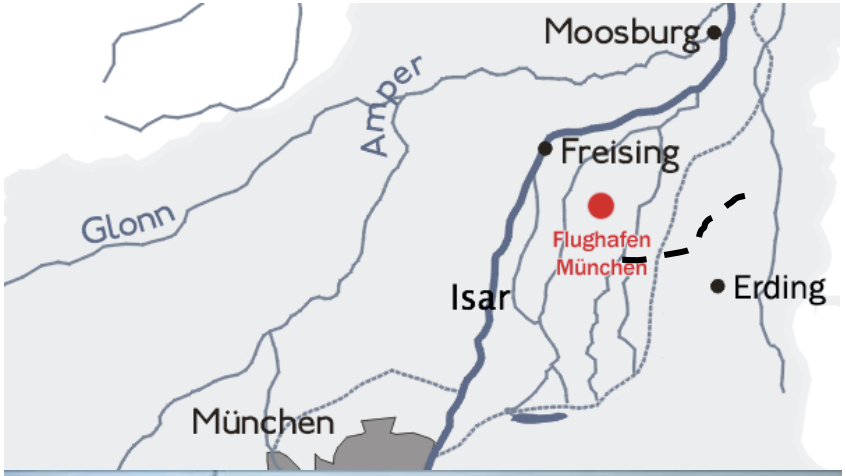

Total length about 60 km

30 km, to be partly renovated

Dry shotcrete technology, cast concrete and foil

In 2007 application of test fields, investigation between

- with polymer modified
- without polymer modification

Decision taken in favor of polymer modified concrete for the rehabilitation

During Application of Polymer Modified Sprayed Concrete and Final Layer

Application of Sprayed Concrete from Boats

Rehabilitation Work with Polymer Modified Concrete

Conclusion:
Polymer-Modified Concrete Offers Concrete Differentiation

Lower w/c ratios, thanks to improved consistency

Excellent workability without separation, improved pumpability

Good compaction properties and compressive strength, lower e-modulus

Excellent adhesion to substrates, e.g. wet tunnel surface

Increased CO_2 resistance - better durability

Significantly reduced crack formation - Water proofing concept

Easy handling in mixing stations as powder od liquid Polymer is available